

COLD-FORMED SPRING HAVING HIGH FATIGUE STRENGTH AND HIGH
CORROSION FATIGUE STRENGTH, STEEL FOR SUCH SPRING,
AND METHOD OF MANUFACTURING SUCH SPRING

5 The present invention relates to a cold-formed spring having high fatigue strength, a type of material for such a spring, and a method of manufacturing such a spring. More specifically, the present invention relates to a cold-formed spring that must have high fatigue strength against corrosive environments, e.g. a suspension spring used in automobiles, and also relates to a type of material for such a spring and a method of
10 manufacturing such a spring.

BACKGROUND OF THE INVENTION

For the purpose of environmental protection and resource conservation, it is now demanded that the amount of harmful substances contained in the exhaust gas emitted from
15 automobiles should be reduced, while it is also desired that automobiles should have better fuel efficiency. To meet such demands, one effective measure is to make the body of the automobile lighter. Accordingly, efforts have been made to make every part of the body as light as possible.

An example of such a body part is the suspension spring, which will contribute to
20 the production of a lightweight body if it has a higher working stress (or design stress). An improvement of the working stress, however, may cause a problem in respect of the fatigue (or durability) of the spring.

Another problem is the corrosion of the spring, which is unavoidable because suspension springs are installed in such locations of the body that are most badly stained
25 with water or mud. Corrosion creates pits (or micro-pores) on the surface of the spring, and

these pits serve as the starting point for the fatigue fracture of the spring.

To address the aforementioned problems, the applicant has filed a Japanese patent application for a “spring having an improved corrosion fatigue resistance”, as disclosed in the Japanese Unexamined Patent Publication No. H11-241143.

5 The aforementioned spring exhibits high durability even under high working stress. In the development of this spring, however, it was assumed that the spring would be hot-formed. If, as in the present invention, the spring is used as a cold-formed material, the spring may have a poorer durability because of an excessive decarburization (i.e., a phenomenon in which carbon content escapes from the surface of the spring when the
10 spring is heated at high temperature).

Accordingly, what remains unsolved is to obtain a specific type of steel for cold-formed springs that has good durability (or fatigue resistance) as well as good corrosion resistance, and a cold-formed coil spring made from the steel.

In view of the aforementioned problems, the present invention intends to provide a
15 cold-formed spring having high fatigue strength (i.e. fatigue resistance or durability) and high corrosion fatigue strength, a specific type of steel material for such a spring, and a method of manufacturing such a cold-formed coil spring.

SUMMARY OF THE INVENTION

20 To address the aforementioned problems, the present invention provides a cold-formed spring having high fatigue strength and high corrosion fatigue strength, which is made of a wire made from a steel material containing, in weight percentage, 0.45 to 0.52% of C, 1.80 to 2.00% of Si, 0.30 to 0.80% of Ni, 0.15 to 0.35% of Cr and 0.15 to 0.30% of V, with Fe substantially constituting the remaining percentage, and which is
25 hardened and tempered by a high-frequency heating process.

In the aforementioned steel material, it is preferable that the percentage of P is 0.025% or lower and the percentage of S is 0.020% or lower.

It is also preferable that the wire has the tensile strength of 1800 to 2000 MPa and a reduction of area of 35% or higher after being hardened and tempered by the high-frequency heating process.

It is also preferable that the wire has a hardness of 50.5 to 53.5 HRC after being hardened and tempered, and the spring is subject to a shot peening process so that the residual stress at 0.2 mm depth from the surface becomes -600 MPa or higher.

The present invention also provides a method of manufacturing a coil spring having high fatigue strength and high corrosion fatigue strength, in which the spring is made from a steel material containing, in weight percentage, 0.45 to 0.52% of C, 1.80 to 2.00% of Si, 0.30 to 0.80% of Ni, 0.15 to 0.35% of Cr and 0.15 to 0.30% of V, with Fe substantially constituting the remaining percentage, and which includes the steps of making a wire from the steel material, hardening and tempering the wire by a high-frequency heating process and cold-coiling the wire into the spring.

It is preferable that the high-frequency heating process includes the steps of hardening the wire at a temperature of 920 to 1040 °C for 5 to 20 seconds, rapidly cooling the wire, and tempering the wire at a temperature of 450 to 550 °C for 5 to 20 seconds. More preferably, the hardening temperature is within the range from 940 to 1020 °C and the tempering temperature is within the range from 480 to 520 °C.

It is also preferable that the wire is rapidly cooled after being tempered.

The present invention also provides a type of steel material for cold-forming a spring hardened and tempered by a high-frequency heating process, which contains, in weight percentage, 0.45 to 0.52% of C, 1.80 to 2.00% of Si, 0.30 to 0.80% of Ni, 0.15 to 0.35% of Cr and 0.15 to 0.30% of V, with Fe substantially constituting the remaining

percentage.

In the steel material, it is preferable that the percentage of P is 0.025% or lower and the percentage of S is 0.020% or lower.

For the cold-formed spring having high fatigue strength and high corrosion fatigue
5 strength according to the present invention, the percentage ranges of the elements of the steel material have been specified on the basis of the following reasons.

Carbon (C): 0.45 to 0.52%

Carbon has the greatest influence on the strength of the steel material, and any steel material for suspension spring must contain 0.45% or more of carbon to have such a
10 strength that provides an adequate durability (or fatigue resistance). However, when the carbon content is higher than 0.52%, the corrosion fatigue strength will deteriorate due to the decrease in the toughness of the material.

Silicon (Si): 1.80 to 2.00%

Similar to carbon, silicon increases the strength of the steel material. Also, in the
15 case of manufacturing a spring, silicon is an important element to increase the sag resistance of the spring. Under normal working conditions for automobiles, the sag of the spring will be noticeable when the silicon content is lower than 0.18%, which may decrease the height of the body. Silicon also promotes the surface decarburization during the heating process. For a spring that is maximally loaded on its surface when used, the
20 decarburization must be primarily considered. When the silicon content is higher than 2.0%, the decarburization will be noticeable during the heating process for hardening. For this reason, the present invention has set the upper limit of the silicon content at 2.0%.

Nickel (Ni): 0.30 to 0.80%

Nickel improves the corrosion resistance of the steel material. In the case of a
25 suspension spring, the nickel content must be 0.30% or higher to provide an adequate

corrosion resistance. Use of more than 0.80% of nickel, however, is not recommendable because it provides no improvement of the corrosion resistance, which is saturated at 0.80%, while it unnecessarily increases the manufacturing cost due to nickel being an expensive element.

5 Chromium (Cr): 0.15 to 0.35%

Similar to nickel, chromium improves the corrosion resistance of the steel material. Furthermore, chromium improves the hardening effect. To provide the steel material with adequate strength, toughness and durability, the heating process must be fully performed. Therefore, the spring must be completely hardened to its core. For this purpose, the steel
10 material according to the present invention contains 0.15% or more of chromium. However, with respect to the diameter of the suspension spring that the present invention concerns, 0.35% of chromium provides a sufficient hardening effect. Percentages higher than that will undesirably increase the residual austenite.

Vanadium (V): 0.15 to 0.30%

15 Vanadium precipitates in the form of fine particles of carbide inside the steel material, which prevents the development of crystal grains during the heating process. The reduction of the grain size is effective in improving the corrosion fatigue resistance as well as the toughness of the steel material. To obtain such effects, the vanadium content must be 0.15% or higher. The percentage, however, needs to be 0.30% or lower because
20 percentages higher than that are likely to promote the development of each vanadium carbide particle rather than increase the precipitation sites of the carbide. The development of vanadium carbide particles may decrease the toughness and the corrosion fatigue resistance.

Phosphorus (P): 0.025% or lower

25 Phosphorus is the first element to precipitate within the grain boundary inside the

steel material and deteriorates the strength of the grain boundary. Since the precipitation of phosphorus decreases the fatigue strength, it is desirable to make the phosphorus content as low as possible. With respect to the process capability of the manufacturing process and the prescribed properties of the spring, the phosphorus content should be preferably
5 0.025% or lower.

Sulfur (S): 0.020% or lower

Inside the steel material, sulfur is combined with manganese into MnS, which is insoluble into the steel material. Since MnS is a soft substance, it is easily extended through rolling or a similar process, which deteriorates the mechanical properties of the
10 steel material. Therefore, in manufacturing the spring, it is preferable to make the sulfur content as low as possible. With respect to the process capability of the manufacturing process and the prescribed properties of the spring, the sulfur content should be preferably 0.025% or lower.

A typical process of manufacturing a cold-formed spring includes the following
15 steps: rolling a material into a wire; changing the diameter of the wire to a predetermined value by drawing or a similar process, if necessary; hardening and tempering the wire; coiling the wire into a spring; and conducting the shot peening and the pre-setting.

The cold-formed spring according to the present invention is manufactured by using a specific type of steel material whose composition satisfies the above-described
20 conditions, and controlling the hardening and tempering process so that the hardness of the spring becomes 50.5 to 53.5 HRC. When the hardness is lower than this range, the spring cannot have sufficient durability (or fatigue-resistance) to be used as a suspension spring. When the hardness is higher than the range, the cold-coiling of the wire will be difficult and the coiling process will cause some quality damages of the spring, such as a surface
25 flaw, surface crack or the deterioration of the toughness due to an excessive working

effect.

According to the present invention, the hardening and tempering is accomplished by a high-frequency heating process. The high-frequency heating makes it possible to rapidly raise the temperature and minimize the surface decarburization. This heating process is also advantageous in that the crystal grains inside the steel material have little time to develop. Furthermore, this heating process provides a relatively easy control of the temperature with good accuracy. These effects are advantageous particularly for the hardening process. In the tempering process, it is also preferable to use a slightly high temperature to shorten the processing time to obtain the same effect (i.e. temper hardness).

10 This preferably improves the sag resistance of the spring.

For example, it is preferable that, in the high-frequency heating process, the steel material is hardened at a temperature of 920 to 1040 °C (more preferably 940 to 1020 °C) for 5 to 20 seconds, then rapidly cooled, and finally tempered at a temperature of 450 to 550 °C (more preferably 480 to 520 °C) for 5 to 20 seconds. The temperatures specified hereby are higher than in the case of the normal furnace heating and accordingly shorten the heating time (or heat-up time), whereby the decarburization, the development of the crystal grains and some other problems are prevented.

Rapid cooling after the tempering is also recommendable because it reduces the unevenness in temper hardness.

20 According to the present invention, the conditions for the shot peening process is regulated so that the residual stress becomes -600 MPa or higher at 0.2 mm depth from the surface. Given this level of compression residual stress at the surface, the spring will have an adequate durability as a suspension spring. The shot peening may be performed either under cold temperature (at room temperature) or warm temperature (at about 250 to 340 °C).

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As described above, the cold-formed spring according to the present invention is manufactured by preparing a steel material having a specific composition and performing a high-frequency heating process under specific conditions. The spring thus manufactured has good corrosion fatigue resistance to be used as a suspension spring. The appropriate
5 determination of the conditions for the heating, shot peening and other subsequent processes minimizes the amount of sag that may arise when the spring is used. Furthermore, the coiling work is facilitated and the quality deterioration due to the coiling work is minimized.

Having the above-described good properties, the cold-formed coil spring according
10 to the present invention can be used under a maximum design stress of 1150 MPa or higher.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a table showing the evaluation result of the decarburization property with
15 respect to the carbon content and the silicon content.

Fig. 2 is a graph showing the optimal region of the carbon content and the silicon content.

Fig. 3 is a graph showing the relation between the carbon content and the corrosion durability.

20 Fig. 4 is a graph showing the relation between the nickel content and the weight loss through corrosion.

Fig. 5 is a graph showing the relation between the vanadium content and the crystal grain size number.

25 Fig. 6 is a graph showing the relation between the phosphorus content and the corrosion durability.

Fig. 7 is a graph showing the relation between the tensile strength and the reduction of area of an example of the steel material according to the present invention and a comparison steel material.

5 DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Examples of the present invention are described with reference to the drawings.

Twenty pieces of steel samples having different carbon and silicon contents were prepared for an investigation of the decarburization property. Each sample was heated for 10 minutes up to 900 °C, which was then rapidly cooled and cut. The cut surface was
 10 observed with a microscope, and the sample was evaluated as either "OK (Good)" (when the depth of the perfect (ferrite) decarburization layer was less than 0.02 mm) or "NG (No Good)" (when the depth was 0.02 mm or more). The result is shown in Fig. 1.

From Fig. 1, the optimal region of the carbon content and the silicon content with respect to the decarburization has been determined, as shown in Fig. 2. The optimal region
 15 corresponds to 0.45 to 0.52% of carbon content and 1.80 to 2.00% of silicon content, in weight percentage.

In Fig. 2, the steel lacks strength within the region with the silicon content lower than 1.80% and the carbon content lower than 0.52%. In this region, the lack of durability causes a considerable amount of sag when the steel is used as a spring. In the region with
 20 the silicon content higher than 2.00%, the decarburization is undesirable. In this region, the surface strength of the steel may significantly decrease due to the decarburization during the heating process. In the region with the carbon content higher than 0.52%, the steel lacks toughness. When, as in the case of the suspension spring, the steel is used under a very corrosive environment, the lack of toughness causes a decrease in the durability.

25 The second experiment focused on the relation between the carbon content and the

corrosion durability. In this experiment, the loading condition was 490 ± 294 MPa. The contents of the principal elements other than carbon were as follows: Si: 1.99%, Mn: 0.69%, Ni: 0.55%, Cr: 0.20% and V: 0.20%. The result of this experiment is shown in Fig. 3.

5 Fig. 3 shows that the number of cycles to failure in the corrosion durability test is greater than 50,000 when the carbon content is 0.52% or lower, meaning that the corrosion durability is adequate. When the carbon content is higher than 0.52%, the number of cycles to failure rapidly decreases to about 30,000 or less.

10 The third experiment focused on the relation between the nickel content and the corrosion resistance. The contents of the principal elements other than nickel were as follows: C: 0.49%, Si: 1.99%, Mn: 0.69%, Cr: 0.20% and V: 0.20%. In the experiment, the process of spraying a saline solution at the temperature of 35 °C onto the sample for 3 hours and drying the sample for 21 hours at the temperature of 35 °C was repeated twenty times. Upon completion, the weight loss through corrosion per unit surface area (kg/m^2)
15 was checked as the criteria for evaluating the corrosion resistance. The result is shown in Fig. 4.

Fig. 4 shows that the weight loss is $0.4 \text{ kg}/\text{m}^2$ when the nickel content is 0.30% or higher, meaning that the corrosion resistance is adequate.

20 The fourth experiment focused on the relation between the vanadium content and the grain-refining effect. The contents of the principal elements other than vanadium were as follows: C: 0.49%, Si: 1.99%, Mn: 0.69%, Ni: 0.55% and Cr: 0.20%. The result is shown in Fig. 5.

25 Fig. 5 shows that the crystal grain size number is greater than 10 when the vanadium content is within the range from 0.15 to 0.30%, meaning that the grain-refining effect is adequate.

The fifth experiment focused on the relation between the phosphorus content and the corrosion durability. The contents of the principal elements other than phosphorus were as follows: C: 0.49%, Si: 1.99%, Mn: 0.69%, Ni: 0.55%, Cr: 0.20% and V: 0.20%. The result is shown in Fig. 6.

5 Fig. 6 shows that the number of cycles to failure in the corrosion durability test is greater than 50,000 when the phosphorus content is 0.025% or lower, whereas the number decreases to about 20,000 or less when the phosphorus content is higher than 0.025%.

The sixth experiment focused on the relation between the tensile strength and the reduction of area of the wire made from a steel material containing 0.49% of C, 1.99% of
10 Si, 0.69% of Mn, 0.55% of Ni, 0.20% of Cr and 0.20% of V. The wire was hardened by a high-frequency heating process and then tempered at various temperatures so that its tensile strength becomes 1800 to 2000 MPa. The relation is shown in Fig. 7, which also shows the property data of a conventional steel material (SAE9254) for comparison. The graph in Fig. 7 clearly shows that the steel material according to the present invention has a
15 higher ductility than the conventional one. This result suggests that the present invention improves the corrosion fatigue resistance.